

NUCLEONICA: Decay Engine J. MAGILL

Nucleonica GmbH
c/o European Commission,
Hermann-von-Helmholtz Platz 1
76344 Eggenstein-Leopoldshafen, Germany



Some theory...

**Launching Decay
Engine...**

**Performing calculation
with default settings...**

**Exploring calculation
results...**

Selecting options...

Plotting results...

Modern Alchemy: Discovery of transmutation, (Soddy 1901)

In 1901, twenty-four year-old chemist Frederick Soddy and Ernest Rutherford were attempting to identify a mysterious gas that wafted from samples of radioactive thorium oxide. They suspected that this gas—they called it an “emanation”—held a key to the recently discovered phenomenon of radioactivity. Soddy had passed the puzzling gas over a series of powerful chemical reagents, heated white-hot. When no reactions took place, he came to a startling realization. As he told his biographer many years later....

‘I remember quite well standing there transfixed as though stunned by the colossal import of the thing and blurting out- or so it seemed at the time: “Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon gas“. Rutherford’s reply was typically aware of more practical implications, “For Mike’s sake, Soddy, don’t call it *transmutation*. They’ll have our heads off as alchemists“

*quoted in *Pioneer*, pp 83-84



Frederic Soddy



Joseph Wright (1734-1797)

Simple radioactive decay..

Basic equation first identified by Rutherford

$$dQ/dt = -kQ \quad (1)$$

Q is the number of atoms, k is the decay constant (probability per unit time that a nucleus will decay):

$$k = \ln 2 / \tau$$

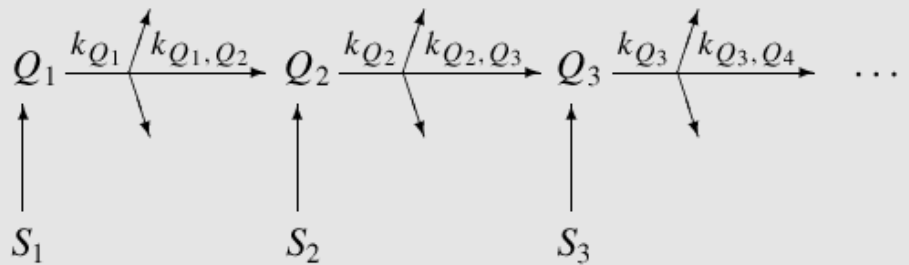
where τ is the half-live. Solution of Eq.1...

$$Q(t) = Q(0) e^{-kt} \quad \text{or} \quad Q(t) = Q(0) 2^{-t/\tau}$$

Activity..

$$A(t) = k Q(t)$$

Successive radioactive decay with branching and source terms



The differential equations governing the above processes:

$$\begin{aligned} dQ_1/dt &= S_1 - k_{Q_1} \cdot Q_1, \\ dQ_2/dt &= S_2 + k_{Q_1, Q_2} \cdot Q_1 - k_{Q_2} \cdot Q_2, \\ dQ_i/dt &= S_i + k_{Q_{i-1}, Q_i} \cdot Q_{i-1} - k_{Q_i} \cdot Q_i, \\ dQ_n/dt &= S_n + k_{Q_{n-1}, Q_n} \cdot Q_{n-1} - k_{Q_n} \cdot Q_i, \end{aligned}$$

Mr. Bateman, Solution of a system of differential equations, etc. 423

The solution of a system of differential equations occurring in the theory of radio-active transformations. By H. BATEMAN, M.A., Trinity College.

[Read 21 February 1910.]

1. It has been shown by Prof. Rutherford * that the amounts of the primary substance and the different products in a given quantity of radio-active matter vary according to the system of differential equations,

$$\left. \begin{aligned} \frac{dP}{dt} &= -\lambda_1 P \\ \frac{dQ}{dt} &= \lambda_1 P - \lambda_2 Q \\ \frac{dR}{dt} &= \lambda_2 Q - \lambda_3 R \\ \frac{dT}{dt} &= \lambda_3 R - \lambda_4 T \\ &\dots\dots\dots \end{aligned} \right\} \dots\dots\dots (1).$$

denote the number of atoms of the primary substance and the various products which are present at time t . He has worked out the various cases in which the products in addition to the primary substance, but as if the results may be extended to any without much labour.

The straightforward method is unsymmetrical, the results of the calculations are needed in which are being carried on in radio-activity, but it is worth while to publish a simple and of obtaining the required formulae. Let us assume a set of auxiliary quantities $p(x)$, $q(x)$, $r(x)$, $s(x)$, ... on a variable x and connected with the $P(t)$, $Q(t)$, $R(t)$, $T(t)$, ... by the equations,

$$p(x) = \int_0^\infty e^{-xt} P(t) dt, \quad q(x) = \int_0^\infty e^{-xt} Q(t) dt, \dots\dots\dots (2).$$

It is easily seen that

$$\begin{aligned} \int_0^\infty e^{-xt} \frac{dP}{dt} dt &= -P(0) + x \int_0^\infty e^{-xt} P(t) dt \dots\dots\dots (3), \\ &= -P_0 + xp, \end{aligned}$$

* Radio-activity, 2nd edition, p. 582.



H. Bateman

Exact solution:

$$Q_n(t) = \sum_{i=1}^{i=n} \left[\left(\prod_{j=1}^{j=n-1} k_{j,j+1} \right) \times \sum_{j=i}^{j=n} \left(\frac{Q_i(0) e^{-k_j t}}{\prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)} + \frac{S_i (1 - e^{-k_j t})}{k_j \prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)} \right) \right]$$

For $S_i = 0$:

$$Q_n(t) = \prod_{j=1}^{j=n-1} k_{j,j+1} \sum_{j=i}^{j=n} \frac{Q_i(0) e^{-k_j t}}{\prod_{\substack{p=i \\ p \neq j}}^n (k_p - k_j)}$$

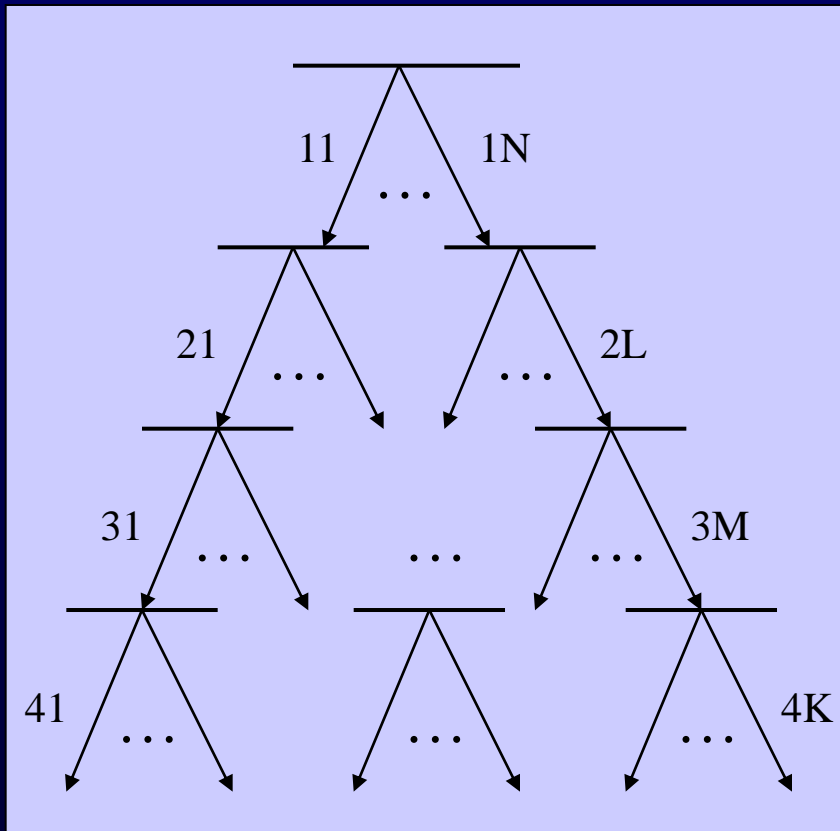
First few terms...

$$Q_1 = Q_1(0) e^{-k_1 t}$$

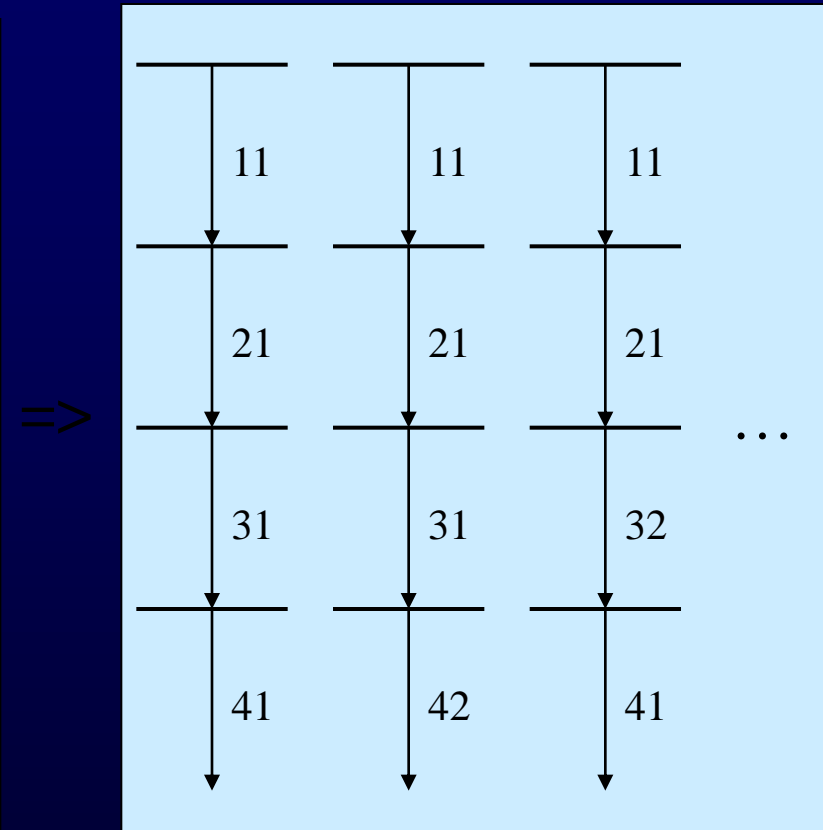
$$Q_2 = k_{1,2} \left\{ \frac{Q_1(0) e^{-k_1 t}}{k_2 - k_1} + \frac{Q_1(0) e^{-k_2 t}}{k_1 - k_2} \right\}$$

$$Q_3 = k_{1,2} k_{2,3} \left\{ \frac{Q_1(0) e^{-k_1 t}}{(k_2 - k_1)(k_3 - k_1)} + \frac{Q_1(0) e^{-k_2 t}}{(k_1 - k_2)(k_3 - k_2)} + \frac{Q_1(0) e^{-k_3 t}}{(k_1 - k_3)(k_2 - k_3)} \right\}$$

Decay Tree



Linear Chains



$$\text{Prod}_1 = \text{BR}_{11} \text{BR}_{21} \text{BR}_{31} \text{BR}_{41}$$



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Applications My Preferences Help

New Alerts

- Nuclide Explorer
- Mass Activity Calculator
- Decay Engine
- Dosimetry and Shielding**
- Range and Stopping Power
- webKORIGEN
- Universal Nuclide Chart
- Transport and Packaging
- Nuclide Mixtures
- Nucleonica Scripting
- Library Creation
- Extended Graph Module
- Physical Constants
- Nuclide Datasheet
- Radiations
- Fission Yields
- Nuclear Data Retrieval
- Nuclear News
- Conference Calendar

Application Centre

- » Mass Activity Calculator
- » Decay Engine
- » **Dosimetry & Shielding**
- » Range & Stopping Power
- » webKORIGEN
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- » Transport & Packaging
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- » Ask An Expert
- » Element Information
- » Conference Calendar

Welcome, Andrey

[Edit Preferences](#)
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My Last Nuclides

- 92 U235
- 43 Tc90
- 52 Te118
- 34 Se81 m
- 73 Ta155

My Nuclide Mixtures

- Transuranics in 1 ton Spent Fuel (4.2% enriched, %50GWd/t, 6 years cooling)
- Cs137+Ba137m
- U232+Co60
- Test_Source_1

My Sources

No sources selected yet

My Messages

- Maintenance Work
- Maintenance Work
- Maintenance Work
- NAMLS-9 International Conference on Nuclear Analytical Methods in the Life Sciences
- Request for photos of non-stable elements

» View

User Alerts

To launch the Decay Engine

click on Decay Engine in the Application Center list.....

or

choose Decay Engine from the Applications dropdown list....



Logged in as: aberizov Home Search Forum Calculator Disclaimer

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Views Applications My Preferences Help New Alerts

Select

Element: Mass:

Po 218

Zoom

View: 5

Select colour theme:

Karlsruhe

☒ alpha ☒ beta- ☒ beta+ ☒ IT ☒ n ☒ SF ☒ p ☒ ec ☒ CE

☒ stable

All None

Background

Rn216 45 μ s	Rn217 540 μ s	Rn218 35 ms	Rn219 3.96 s	Rn220 55.8 s	Rn221 25 m	Rn222 3.82 d
At215 100 μ s	At216 300 μ s	At217 32.3 ms	At218 1.5 s	At219 54 s	At220 3.71 m	At221 2.3 m
Po214 1.6E2 μ s	Po215 1.78 ms	Po216 150 ms	Po217 1.47 s	Po218 3.1 m	Po219 2 m	Po220 40 s
Bi213 45.59 m	Bi214 19.9 m	Bi215 36.9 s 7.4 m	Bi216 2.17 m	Bi217 1.84 s		
Pb212 10.64 h	Pb213 10.2 m	Pb214 26.8 m	Pb215 36 s			

Ground state: 3127 nuclides from 3127 Metastable: 769 nuclides from 769 Total: 3896 nuclides from 3896

To launch the Decay Engine

select nuclide of interest in the Nuclide Explorer page.....

then

click right mouse button over it

and

choose Decay Engine from the list, which will appear

.....

nucleonica

Applications My Preferences Print

Po218
3.1 m

Decay Engine
84 Polonium

Actual Chart: Karlsruhe

Element: Mass:
Po 218 Nuclide Mixtures Selector

Decay Engine Options

Quantity: Grams 1
Time: Minutes 3.10E+01

Start Start in background Reset

Quantity: Grams
Time: Minutes

Start Start in background

Type of graph: Numbers

Version 1.0.0000.0090

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Applications My Preferences Print Help New Alerts

Po218
3.1 m

Decay Engine
84 Polonium

Actual Chart: Karlsruhe

Element: Mass:
Po 218 Nuclide Mixtures Selector

Decay Engine Options

Quantity: Grams 1
Time: Minutes 3.10E+01

Start Start in background Reset

Parent+Daughters	Half-life	BR
84 Po218	3.1 m	0.99981; 1.90E-08
82 Pb214	26.8 m	1
83 Bi214	19.9 m	0.99979; 2.11E-08
84 Po214	1.6E2 μ s	1
82 Pb210	22.17 y	1; 1.90E-08
83 Bi210	5.01 d	0.999999; 1.00E-08
84 Po210	1.4E2 d	1
82 Pb206 Stable	stable	
Total:		

84 Po218
82 Pb214
83 Bi214
84 Po214
82 Pb210
83 Bi210
84 Po210
82 Pb206 Stable
Total:

Update

Download Excel CSV Separator: Semicolon

Type of graph: Numbers

Number of atoms

t [Minutes]

Show Graph Settings
Print
Download

Start a calculation using default values....

Element Info in Nucleonica wiki

Nuclide selection tools

Mass-activity calculator

Set the time

Select the value to be plotted on a graph

Set the number of timesteps. To plot a graph up to 40 timesteps can be used

Set the accuracy of the calculation. Default value 1E-2 gives at least the main chain. **Zero value gives all chains!**

Number of chains with Accuracy Factor > 1E-2

The screenshot displays the Nucleonica web application interface. At the top, the header includes the Nucleonica logo and navigation links: Applications, My Preferences, Print, and Help. A sidebar on the left shows a list of elements, with Polonium (Po) selected. The main content area features a 'Decay Engine' section for 84 Polonium, showing a decay chain graph and a table of nuclides. The table lists various isotopes of Polonium and other elements, such as Rn216, Rn217, Rn218, Rn219, Rn220, Rn221, Rn222, Rn223, Al215, Al216, Al217, Al218, Al219, Al220, Al221, Al222, Po214, Po215, Po216, Po217, Po218, Po219, and Po220, along with their half-lives. A 'Nuclide Mixtures' section lists several mixtures, including Cs137+Ba137m, Cs137+Ba137m, Test_Source_1, Transuramics in 1 ton Spent Fuel (4.2% enriched, %50GWd/t, 6 years cooling), and U232+Co60. A 'Mass-activity calculator' section is also visible. The bottom of the interface contains a 'Polonium Po' article snippet, which describes the element's discovery and properties. Red boxes and arrows highlight various features: the 'Element Info in Nucleonica wiki' box points to the 'Polonium Po' article; the 'Nuclide selection tools' box points to the 'Decay Engine' section; the 'Mass-activity calculator' box points to the 'Mass-activity calculator' section; the 'Set the time' box points to the 'Time' dropdown menu; the 'Select the value to be plotted on a graph' box points to the 'Numbers' dropdown menu; the 'Set the number of timesteps' box points to the 'Timesteps' dropdown menu; the 'Set the accuracy of the calculation' box points to the 'Accuracy' dropdown menu; and the 'Number of chains with Accuracy Factor > 1E-2' box points to the 'Number of chains' dropdown menu.

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New Alerts

Applications My Preferences Print Help

Po218 3.1 m

Decay Engine

84 Polonium

Actual Chart: Karlsruhe

Element: Mass: Po 218

Select colour the Karlsruhe alpha

Nuclide Mixtures:

Cs137+Ba137m

Cs137+Ba137m

Test_Source_1

Transuramics in 1 ton Spent Fuel (4.2% enriched, %50GWd/t, 6 years cooling)

U232+Co60

Polonium Po - NucleonicaWiki - Micros

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Address http://www.nucleonica.net:81/wiki/index.php/Polonium_Po

Aberlizov my talk preferences my watchlist my contributions log out

article discussion edit history move watch

nucleonica Polonium Po

Polonium

(Poland, native country of Mme. Curie). Polonium was the first element discovered by Mme. Curie in 1898 while seeking the cause of radioactivity of pitchblend from Joachimsthal, Bohemia. The electroscope showed it separating with bismuth. Polonium is also called Radium F. Polonium is a very rare natural element. Uranium ores contain only about 100 micrograms of the element per ton. Its abundance is only about 0.2% of that of radium. In 1934, it was found that when natural bismuth (^{209}Bi) was bombarded by neutrons, ^{210}Bi , the parent of polonium, was obtained. Milligram amounts of polonium may now be prepared this way, by using the high neutron fluxes of nuclear reactors. Polonium-210 is a low-melting, fairly volatile metal, 50% of which is vaporized in air in 45 hours at 55°C. It is an alpha emitter with a half-life of 138.39 days. A milligram emits as many alpha particles as 5 g of radium. The energy released by its decay is so

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nucleonica

Po218
3.1 m

Decay Engine 84 Polonium

Actual Chart: Karlsruhe

1
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
84 Po214 1.15E+14
82 Pb210 5.25E+20
83 Bi210 3.28E+14
84 Po210 2.39E+11
82 Pb206 Stable 3.21E+06
Prod = 1.00E+00
Total = 2.76E+21

2
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
81 Ti210 1.12E+16
82 Pb210 9.90E+16
83 Bi210 5.79E+10
84 Po210 3.98E+07
82 Pb206 Stable 4.23E+02
Prod = 2.10E-04
Total = 2.24E+21

3
84 Po218 2.71E+18
85 At218 4.19E+12
83 Bi214 2.11E+17
84 Po214 2.89E+10
82 Pb210 3.13E+17
83 Bi210 2.90E+11
84 Po210 2.76E+08
82 Pb206 Stable 6.41E+03
Prod = 1.90E-04
Total = 3.23E+18

4
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
82 Pb210 1.57E+16
83 Bi210 9.85E+09
84 Po210 7.17E+06
82 Pb206 Stable 1.17E+02
Prod = 3.00E-05
Total = 2.24E+21

5
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
84 Po214 1.15E+14
82 Pb210 5.25E+20
83 Bi210 3.28E+14
81 Ti206 1.50E+05
82 Pb206 Stable 1.65E+05
Prod = 1.32E-06
Total = 2.76E+21

6
84 Po218 2.71E+18
85 At218 4.19E+12
86 Rn218 9.77E+07
84 Po214 4.57E+05
82 Pb210 5.24E+14
83 Bi210 8.25E+08
84 Po210 1.08E+06
82 Pb206 Stable 3.39E+01
Prod = 1.90E-07
Total = 2.71E+18

7
84 Po218 2.71E+18
85 At218 4.19E+12
83 Bi214 2.11E+17
81 Ti210 3.09E+12
82 Pb210 6.26E+13
83 Bi210 5.40E+07
84 Po210 4.82E+04
82 Pb206 Stable 1.11E+00
Prod = 3.99E-08
Total = 2.92E+18

8
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
84 Po214 1.15E+14
82 Pb210 5.25E+20
80 Hg206 3.63E+06
81 Ti206 1.19E+06
82 Pb206 Stable 1.42E+06
Prod = 1.90E-08
Total = 2.76E+21

9
84 Po218 2.71E+18
82 Pb214 1.40E+21
83 Bi214 8.35E+20
81 Ti210 1.12E+16
82 Pb209 6.69E+12
83 Bi209 2.36E+11
81 Ti205 Stable 0.00E+00
Prod = 1.47E-08
Total = 2.24E+21

10
84 Po218 2.71E+18
85 At218 4.19E+12
83 Bi214 2.11E+17
82 Pb210 9.39E+12
83 Bi210 8.71E+06
84 Po210 8.28E+03
82 Pb206 Stable 0.00E+00
Prod = 5.69E-09
Total = 2.92E+18

Accuracy Factor: 0

Number of timesteps: 10

Number of chains: 23

Reset

Show Details

Create Nuclide Mixture

	Decay	N(atoms)	M(g)	A(Bq)
		2.76E+21	9.78E-01	1.58E+18
	β^-	1.40E+21	4.97E-01	6.03E+17
99979; 2.10E-04; 3.00E-05	β^- ; α ; β^- , α	8.36E+20	2.97E-01	4.85E+17
	α	1.15E+14	4.07E-08	4.85E+17
99981; 1.90E-04	α ; β^-	2.71E+18	9.81E-04	1.01E+16
99993; 7.00E-05	β^- ; β^- , n	1.12E+16	3.91E-06	9.97E+13
999; 1.00E-03	α ; β^-	4.19E+12	1.52E-09	1.94E+12
1.90E-08	β^- ; α	5.25E+20	1.83E-01	5.20E+11
	α	9.77E+07	3.54E-14	1.94E+09
999999; 1.32E-06	β^- ; α	3.29E+14	1.15E-07	5.26E+08
	β^-	6.70E+12	2.32E-09	3.96E+08
	α	2.39E+11	8.35E-11	1.39E+04
	β^-	3.64E+06	1.24E-15	5.16E+03
	β^-	1.34E+06	4.58E-16	3.68E+03
	α	2.36E+11	8.21E-11	2.73E-16
		4.80E+06	1.64E-15	0
		0	0	0

Semicolon (",")

☒ Use field qualifier ("")

Click on the column title to arrange the data in ascending /descending order on the parameter chosen



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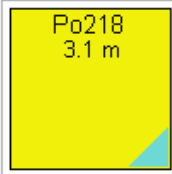
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Decay Engine

84 Polonium

Actual Chart: Karlsruhe

Element: Mass:

Po

218



Nuclide Mixtures Selector

Decay Engine

Options

Decay Engine Settings

- | | | | |
|---|--|---|---|
| <input checked="" type="checkbox"/> Halflives | <input checked="" type="checkbox"/> Masses | <input type="checkbox"/> Gamma Emission Rate | <input type="checkbox"/> Isotopic Power (α) |
| <input checked="" type="checkbox"/> Branching Ratio | <input checked="" type="checkbox"/> Activities | <input type="checkbox"/> Spontaneous Fission Rate | <input type="checkbox"/> Isotopic Power ($\alpha+\beta$) |
| <input checked="" type="checkbox"/> Decay Mode | <input type="checkbox"/> Activities (alpha) | <input type="checkbox"/> Ingestion Radiotoxicity | <input type="checkbox"/> Isotopic Power ($\alpha+\beta+\gamma$) |
| <input checked="" type="checkbox"/> Numbers | <input type="checkbox"/> Activities (beta) | <input type="checkbox"/> Inhalation Radiotoxicity | |

Version 1.0.0000.0090

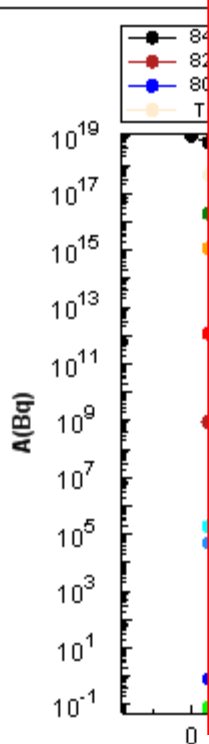
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Radiotoxicity (Sv) = Activity · $e(50)$, where $e(50)$ - effective dose coefficient, which accounts for radiation and tissue weighting factors, metabolic and biokinetic information.

the heat generated per unit time by the decay radiations (W)

Type of graph: Activities ▼

- ☒ 84 Po218
- ☒ 85 At218
- ☒ 86 Rn218
- ☒ 84 Po214
- ☒ 82 Pb210
- ☒ 83 Bi210
- ☒ 84 Po210
- ☐ 82 Pb206 Stable
- ☒ 81 Tl206
- ☒ 80 Hg206
- ☐ 83 Bi214
- ☒ 81 Tl210
- ☒ 82 Pb209
- ☐ 83 Bi209
- ☐ 81 Tl205 Stable
- ☒ 82 Pb214
- ☒ Total:



General Graph Settings

Image Width: Image Height:

Line Style:

Line with Symbols ▼

- ☒ Border
- ☒ Graph Border
- ☒ Show Legend

Titles

Graph Title:

Category (X):

t [Days]

Value (Y):

A(Bq)

Axes

Axis	Type	Min	Max
Y	<input type="radio"/> linear	<input type="text" value="0.2904"/>	<input type="text" value="1.03E+19"/>
	<input checked="" type="radio"/> log	<input checked="" type="checkbox"/> Auto scale Y	
X	<input checked="" type="radio"/> linear	<input type="text" value="0"/>	<input type="text" value="0.0215"/>
	<input type="radio"/> log	<input checked="" type="checkbox"/> Auto scale X	

Gridlines and Ticks

Category (X) Axis

- ☐ Major Gridlines
- ☐ Minor Gridlines

Value (Y) Axis

- ☐ Major Gridlines
- ☐ Minor Gridlines

Ticks Location:

- ☐ Outside scale
- ☒ Inside scale
- ☐ Through scale

Tick Steps:

X Axis: Major Step Minor Step

- ☒ Auto set steps

Y Axis: Major Step Minor Step

- ☒ Auto set steps

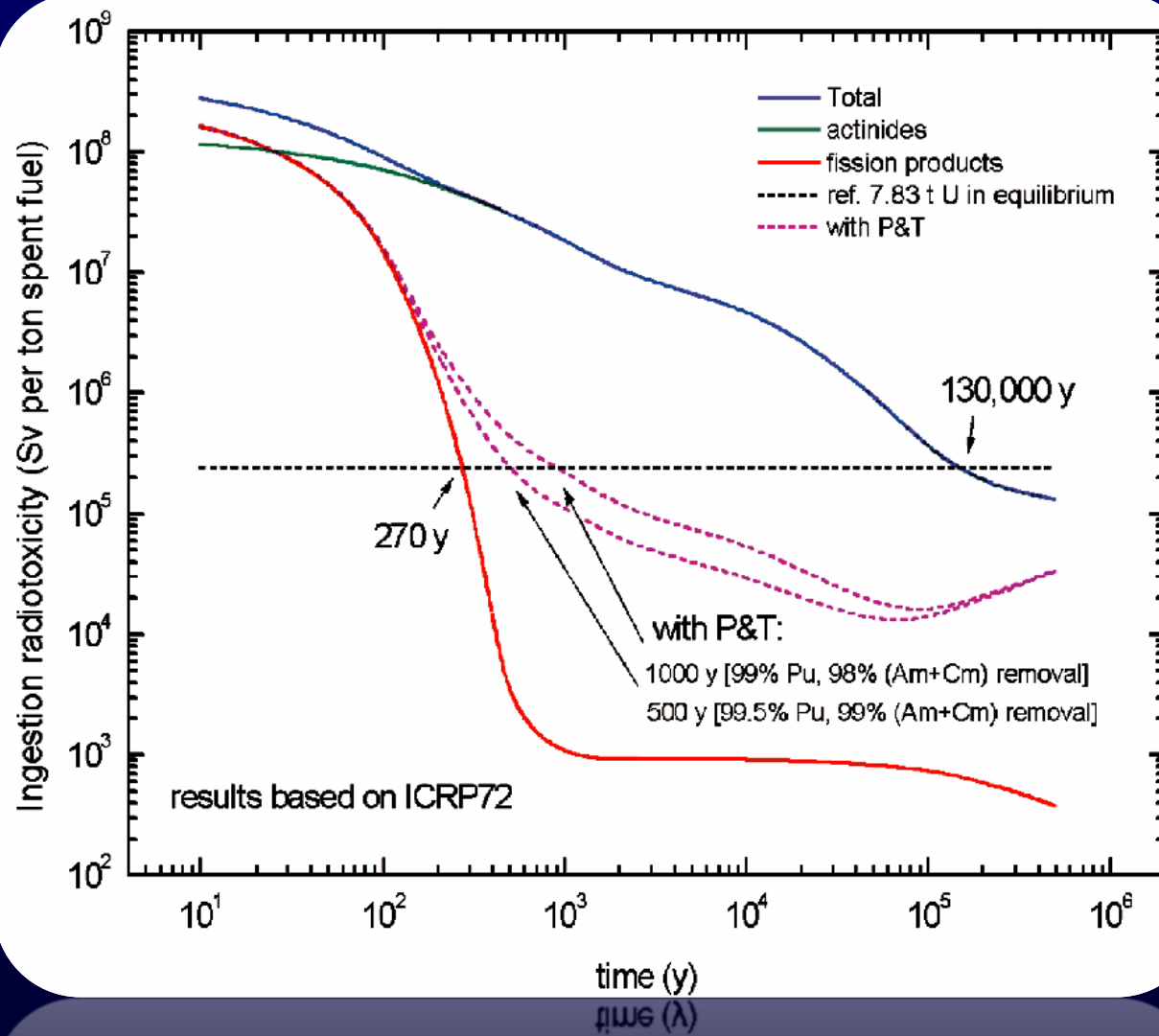
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Some theory...

**Launching Decay
Engine...**

**Performing calculation
with default settings...**

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Selecting options...

Plotting results...

Thanks!

